Comparative Study of Wastewater Lagoon with and without Water Hyacinth[1]

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A 3-year study was conducted on an existing, one-cell, facultative sewage lagoon having a total surface area of 3.6 ha and receiving a BOD_5 loading rate of 44 kg/ha/d (40 lb/a/d). The comparative experimental periods ran from July through November for 3 consecutive years. During the first period, water hyacinths completely covered the lagoon. The water hyacinth coverage was reduced to 33% of the total surface area the second year. The lagoon, free of all vascular aquatic plants the third year, was monitored for comparative purposes. The most significant improvement overall in the effluent quality occurred when water hyacinths covered the entire lagoon. During this period the effluent BOD_5 and TSS were 23 and 6 mg/l, respectively. Without water hyacinths, the effluent BOD_5 and TSS were 52 and 77 mg/l, respectively. The effluent total organic carbon concentration with water hyacinths averaged 40 mg/l, and without water hyacinths, 72 mg/l. A discussion of the results from this 3-year study is presented in this paper along with associated problems that were observed when water hyacinths were introduced into the lagoon and altered its behavior from that of a normal facultative lagoon.

In recent years all wastewater treatment systems have come under more critical examination and more stringent discharge requirements. Consequently, a large percentage of communities, especially those with wastewater treatment lagoons, have been required to upgrade their existing facilities. One new method that has been the focus of several, recent research projects involves the use of vascular aquatic plants as the principal, biological filtration agent. Water hyacinth (*Eichhornia crassipes*), in particular, has received much attention because of its hardiness and high productivity, especially when grown in domestic sewage lagoons. This floating, aquatic plant has an extensive root system that allows the plant to absorb nutrients directly from the water. In favorable climates and nutrient-enriched waters, this plant can grow to over 1 m in height above the water surface. Since this plant reproduces mainly by vegetative means, it can continuously produce offspring and new plant material following partial harvesting without the need of restocking. Pieterse (1978) recently wrote a comprehensive review of the available literature on the water hyacinth.

Steward (1970) and Boyd (1970) suggested that the water hyacinth was an excellent candidate for large nutrient removal systems based on theoretical projections from observed plant nutrient content, and Westlake's (1963) estimated potential hyacinth productivity of 150 mt/ha/yr. Wolverton and McDonald (1978) later projected an annual productivity of 154 mt/ha from growth rate studies at the lagoon investigated in this report. Projections of this nature were further substantiated in actual nutrient removal studies. In one such study Sheffield (1967) found that his laboratory-scale system, which consisted of a water hyacinth pond

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followed by air stripping and coagulation and receiving 8.0 l/day of treated wastewater, could reduce the o-PO_4^{-3}-P to 0.7 mg/l, the NO_3^--N to 0.2 mg/l, and the NH_4^+-N to 0.1 mg/l. The results from a study by Rogers and Davis (1972), using water hyacinths in both static and flowing systems, when interpreted with the productivity results of Penfound and Earle (1948), indicated that a 1-a water hyacinth treatment system could remove the daily nitrogen and phosphorus wastes of 800 people. Field tests by Dunigan et al. (1975) indicated that the water hyacinth was more effective in removing NH_3^+-N than NO_3^--N. Ornes and Sutton (1975) conducted phosphorus removal experiments using water hyacinths and static sewage effluent. A maximum uptake of 5.50 μg P/g (dry weight) of plant material was observed from wastewater containing 1.1 mg P/l. Promising results pertaining to the nutrient removal ability of the water hyacinth from treated sewage effluent were also obtained by Cornwell et al. (1977).

More recently water hyacinths have been used to upgrade full size domestic sewage lagoons. In a study, Dinges (1978) used the water hyacinth as a final treatment system to upgrade the effluent from a large system consisting of an activated sludge plant and two aerated basins operating in parallel followed by three stabilization ponds. The 5-day biochemical oxygen demand (BOD_5) loading in the water hyacinth experimental pond was varied from 42.1 to 86.8 kg/ha/d. Throughout the experiment, the BOD_5 and total suspended solids (TSS) of the effluent averaged less than 10 mg/l each. The total nitrogen concentration was reduced to less than 5 mg/l.

For the past 5 years the National Aeronautics and Space Administration (NASA) at the National Space Technology Laboratories (NSTL) in south Mississippi has sponsored research on the use of the water hyacinth in wastewater treatment and the production of biomass for food, feed, fertilizer, and energy. A review was recently written by Wolverton and McDonald (1979a) on NASA's vascular aquatic plant program. One study (Wolverton and McDonald, 1976) involved introducing water hyacinth into a facultative pond which received the discharge from 2, series aerated lagoons. The pond was used in a polishing mode to upgrade the water quality, especially in terms of lowering suspended solids concentration, in order to meet permit requirements. In this experiment the yearly mean TSS and BOD_5 were each reduced to 14 mg/l each. In another study, water hyacinth was introduced into a 1-cell, facultative waste treatment pond (Wolverton and McDonald, 1979b). With water hyacinths, the mean total suspended solids in the effluent were reduced to 10 mg/l due to the virtual elimination of algae. The BOD_5 was reduced by an average of 94% to a mean of 5.4 mg/l prior to discharge.

The 3-year study presented in this paper is a continuation of NASA's efforts at NSTL to develop a data base sufficiently extensive to make it possible to predict with confidence the impact of the introduction of water hyacinth on an existing, full-scale domestic sewage lagoon. During the first summer of the study reported herein, the sewage lagoon was totally covered with water hyacinths; during the second summer, the lagoon was partially covered with these plants; and during the third consecutive summer, the lagoon was free of water hyacinth and all other vascular aquatic plants. Year-round growth of the water hyacinth could not be maintained since the system was completely open and some freezing occurs during the winter.

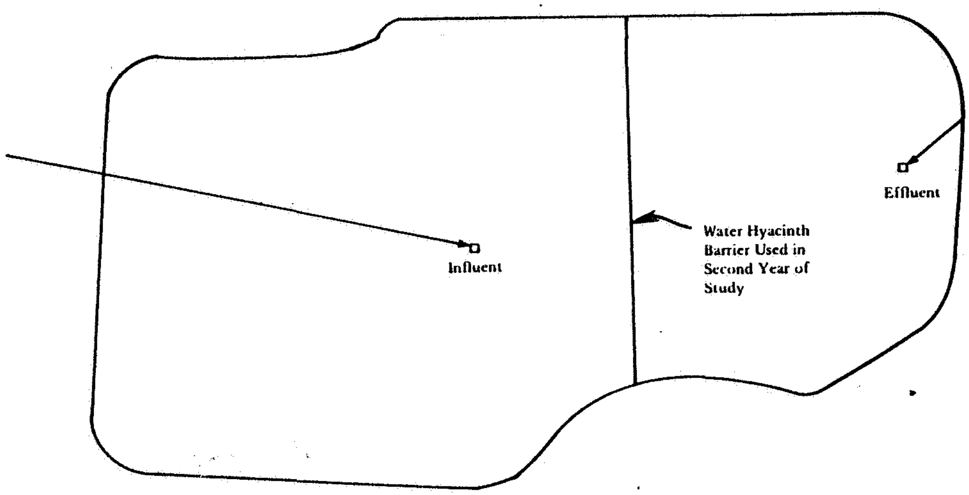

Fig. 1. Lucedale sewage lagoon.

SYSTEM DESCRIPTION

The facultative lagoon used in the present study served to treat the wastewater from the small community of Lucedale, Mississippi, with an approximate population of 2,500. The configuration of the pond is diagramed in Fig. 1. The lagoon has a surface area of 3.6 ha (9 a) and an average depth of 1.73 m (68 in). During the first year of study, water hyacinths were introduced into the lagoon in April. By the first of July the plants had completely covered the lagoon. In mid-August approximately 10% of the water hyacinths were harvested. The remaining plants were left unprotected through the winter. By December, the water hyacinth tops were badly damaged by frost. Freezing weather in January and February further damaged the plants, and many began to sink. The following spring the plants that resprouted were confined by a floating barrier to approximately 1.2 ha (3 a) at the effluent point. These plants covered the entire barricaded area by July and remained unharvested throughout the summer. In early spring of the third year, all water hyacinths were harvested from the lagoon. No water hyacinths have been observed in the lagoon for over a year since they were harvested.

SAMPLING AND ANALYSES

Influent and effluent grab samples were taken twice a week. These samples were analyzed according to the American Public Health Association (1975) for the following parameters: total dissolved and suspended solids (TDS and TSS), using standard glass fiber filters to determine the filtrable and nonfiltrable residues; 5-day biochemical oxygen demand (BOD_5), using the membrane electrode method to determine the dissolved oxygen concentrations; and pH, using a combination electrode. Kjeldahl nitrogen and total phosphorus were determined with an autoanalyzer after digestion with a $H_2SO_4/K_2SO_4/HgSO_4$ solution. Total organic carbon (TOC) was determined with the combustion-infrared method using a TOC analyzer. The dissolved oxygen was measured in situ with a membrane electrode and portable oxygen meter. The effluent flow rates were monitored 5 days a week

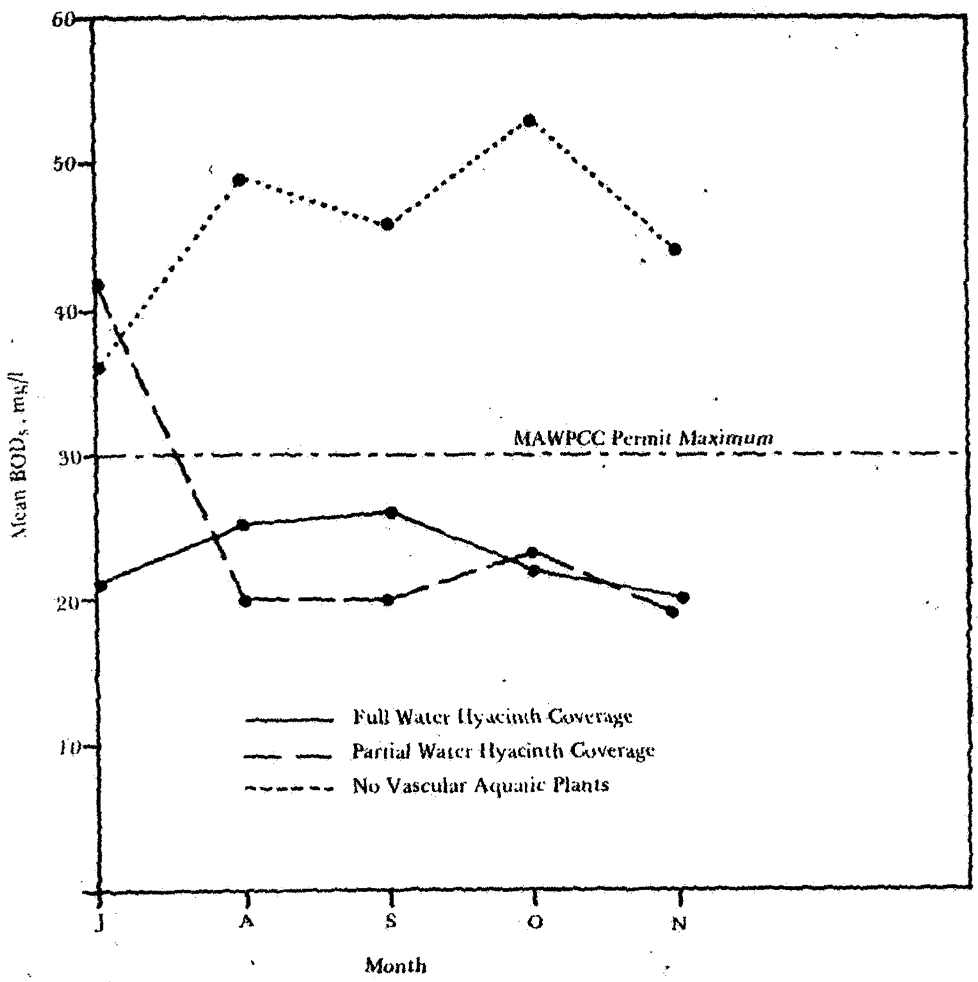

Fig. 2. Monthly mean 5-day biochemical oxygen demand concentrations during the 3 study periods.

by the city of Lucedale with the use of a calibrated weir at the point of discharge. Accurate measurement of total daily influent volumes was not possible.

RESULTS

The two most important parameters for determining water quality are BOD_5 and TSS. For the Lucedale wastewater treatment system, the Mississippi Air and Water Pollution Control Commission (MAWPCC) has set mean monthly maximum discharge requirements of 30 mg/l each on BOD_5 and TSS. The average data for the months of July through November of each year during this 3-year study period is presented in Table 1.

One very interesting result was observed with the BOD_5 removal as shown in Fig. 2. Except for July, partial water hyacinth coverage was almost as effective in reducing the BOD_5 as total coverage. With total coverage the mean effluent

TABLE 1. FIVE-MONTH EXPERIMENTAL MEANS FOR EACH PARAMETER DURING THE 3 CONSECUTIVE YEAR STUDY PERIODS.

	Five-month mean					
	100% WH coverage		33% WH coverage		0% WH coverage	
Parameter	Inf	Eff	Inf	Eff	Inf	Eff
BOD_5, mg/l	161	23	121	25	127	52
TSS, mg/l	125	6	85	57	140	77
TKN, mg/l	30.3	14.4	26.2	14.8	28.2	18.7
TP, mg/l	8.5	7.9	7.8	8.2	8.1	8.6
TOC, mg/l	93	40	73	60	66	72
DO, mg/l	1.5	0.6	2.2	0.8	2.1	4.4
pH	7.3	7.0	7.1	7.1	7.3	7.7
Discharge, m^3/day		935		1,240		957

BOD_5 ranged from 21–26 mg/l; with partial coverage it varied from 19–42 mg/l; with no water hyacinths, the mean effluent BOD_5 ranged from 36–79 mg/l. Assuming the mean annual rainfall for Lucedale approximately equals the total evaporation and any seepage losses, the total BOD_5 removal effectiveness can be estimated based on mean BOD_5 concentrations and daily discharge volumes. For Lucedale, the annual evaporation is 117 cm (46 in), the monthly evaporation rate for May through October is 13.2 cm (5.2 in) per month, and the annual rainfall averages 160 cm (63 in) (Chow, 1964). The annual rainfall during 1977 was almost two times higher than normal. The run-off from this rain is routed through the sewer lines. The sewage is diluted by this rainfall, but the total mass of BOD_5, nutrients, etc., are independent of the rainfall when the concentration and total volume are both measured.

The average BOD_5 removal rates over the 5-month comparison periods can be seen in Table 1. From these data, the ratio of the mean total masses of BOD_5 removed per day of the 100%:33%:0% water hyacinth coverage was 1.8:1.7:1 (Table 2). The ratio of BOD_5 removed does not include any concentration effects due to transpiration by the water hyacinths. One evapotranspiration study by Timmer and Weldon (1967) found that evapotranspiration losses of water from complete water hyacinth coverage was 3.7 times greater than the water losses due only to evaporation. Based on the research by Timmer and Weldon (1967) and the average evaporation rate for Lucedale, the total daily discharge volume when water hyacinths completely covered the lagoon should have been approximately 46% greater. With reduced coverage the next year and increased flow rates, the daily discharge volume should have been 12% greater. Therefore, the

TABLE 2. TOTAL BOD_5 REMOVED PER DAY AVERAGED FOR EACH 5-MONTH STUDY PERIOD FOR THE 3 YEARS.

Water hyacinth coverage %	Mean 5-month BOD_5 reductions, kg/day
100	129
33	119
0	72

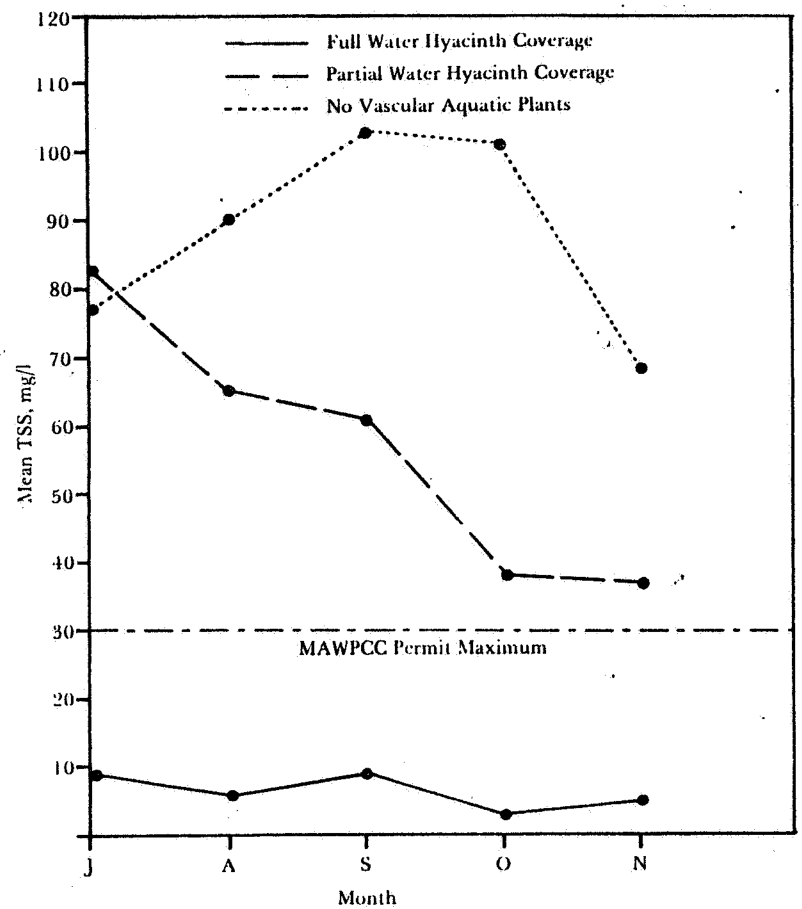

Fig. 3. Monthly mean total suspended solids concentrations during the 3 study periods.

BOD_5 removal efficiency of this lagoon was at least doubled by the water hyacinths when coverage was complete.

The mean TTS's are graphically compared in Fig. 3. When water hyacinth coverage was complete, the total suspended solids were reduced by an average of 95% to an effluent concentration range of 3–9 mg/l and reliably remained below the MAWPCC standard of 30 mg/l. Partial coverage did not affect the desired results on TSS. Lagoon operation with only one-third coverage allowed the algae adequate time to become well established as reflected in the mean effluent TSS concentration of 37–83 mg/l. Even higher TSS concentrations of 26–113 mg/l were routinely discharged when the lagoon was operated in a normal, facultative mode.

The reduction in suspended solids was also reflected in the total organic carbon concentrations as shown in Table 1 and Fig. 4. When water hyacinth coverage was complete the TOC was reduced by 57% from 93 to 40 mg/l. Partial coverage reduced the TOC by 18% from 73 to 60 mg/l. An increase in TOC from 66 to 72 mg/l was noted when no vascular aquatic plants were in the lagoon. This was due to an increase in algal growth which added to the organic matter discharged in the effluent.

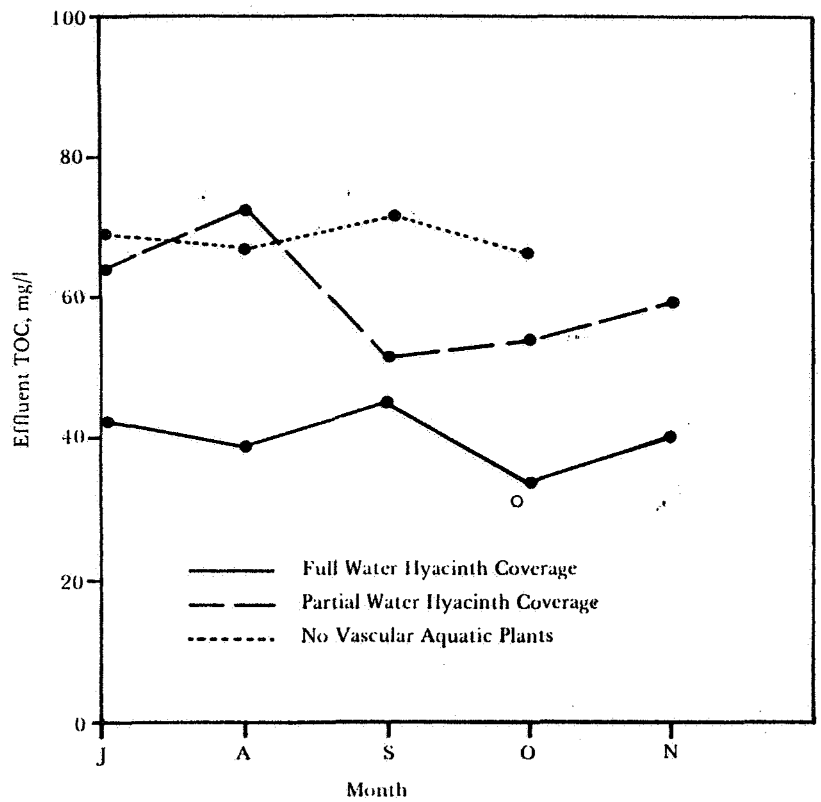

Fig. 4. Monthly mean total organic carbon (TOC) concentrations during the 3 study periods.

When water hyacinths were present, the lack of algae (which oxygenate the pond through photosynthesis) caused the pond to be almost totally anaerobic. In Table 1, the effluent mean dissolved oxygen (DO) concentrations of 0.6 and 0.8 mg/l for total and partial coverage, respectively, show that only trace levels of oxygen remained in the pond. The pond effluent was also dark in color and emitted odors at night when the plants were photosynthetically inactive and did not remove the sulfur-containing gases, such as hydrogen sulfide. This problem could be corrected through minimal aeration at night. When the lagoon was restored to its normal, facultative mode, the DO concentrations in the effluent increased. However, it must be noted that this lagoon, like most heavily loaded facultative lagoons, was not entirely free of odors when water hyacinth was not present. In almost all lagoons of this type, the algae in the warm months sporadically and for no apparent reason undergo prolific growth periods called "blooms," usually followed by large die-offs of the algae cells which create a high BOD and cause the lagoons temporarily to go anaerobic and emit odors.

The pH of the effluent showed very little fluctuation in either of the two experimental periods involving water hyacinth. The pH remained within 0.2 pH units of 7.0 for each of the first two periods. The pH which averaged 7.7 during the last experimental period was more variable when algae were the dominant plants in the system. This is normal behavior for a facultative pond, especially during the spring and summer.

The nutrient data for phosphorus and Kjeldahl nitrogen (organic nitrogen plus ammonia nitrogen) are presented in Table 1 for supplementary information. The data are of limited use since the water hyacinth was not harvested to achieve maximum productivity. When water hyacinths did not cover the lagoon, a slight increase in phosphorus in the effluent was observed for the latter, two experimental periods. This is not an unusual phenomenon, especially since the lagoon is several years old and has accumulated up to 6 in of sludge in some areas of the lagoon. Nutrients from the settled solids are slowly released as anaerobic breakdown occurs in the sludge layer.

The only insect problem encountered in this study was due to one of the most common enemies of the water hyacinth, the spider mite (*Bryobia praetiosa*). Interestingly, there was a significant infestation of this insect the first year, and hardly any spider mites reappeared the second year. This insect was controlled through aerial spraying of malathion. The infestation of spider mites the second year never became severe enough to require spraying.

DISCUSSION

When water hyacinth coverage was complete, the pond was almost entirely anaerobic with only traces of dissolved oxygen near the surface in the water hyacinth root zone. This effect is a usual phenomenon when water hyacinth shades out all algal growth and inhibits natural aeration from photosynthesis and wind action. This condition encouraged odors at night when the water hyacinths were not absorbing the sulfur-containing compounds. The BOD_5 loading rate on the lagoon when water hyacinths were present was 44 kg/ha/d (40 lb/a/d). In an earlier study with a similar system receiving a mean BOD_5 loading rate of 26 kg/ha/d (24 lb/a/d), there were no odor problems when water hyacinths completely covered the lagoon. When the effluent dissolved oxygen concentration was checked after the discharge had tumbled over the outflow, it had increased to 3.5–5.0 mg/l.

Since the lagoon remained in an anaerobic condition and the water hyacinths obviously flourished in this environment, as indicated in a potential water hyacinth productivity study (Wolverton and McDonald, 1978) conducted simultaneously in this lagoon, the water hyacinths obtained most of their nitrogen in a reduced state such as ammonia. The nitrogen forms were either reduced in the anaerobic environment or used directly by the plants instead of undergoing nitrification to nitrite and nitrate, a process which requires free oxygen. Algae have long been recognized for their ability to use ammonia and eliminate the need for nitrification in an aerobic or facultative lagoon (Gloyna, 1971). Also the water hyacinth effected a significant reduction in BOD_5 by directly absorbing and metabolizing oxygen-demanding organics. Because the process of anaerobic degradation requires a longer period of time for completion than aerobic decay, an anaerobic lagoon with approximately the same organic loading rate and detention time as an aerobic lagoon will not reduce the BOD_5 as effectively. Therefore, the significant increase in BOD_5 removal when water hyacinth covered the lagoon and caused the lagoon to go anaerobic was due to the plant removing organics as well as ammonia.

The most effective way of reducing the suspended solids in a lagoon with water hyacinth is to allow the plant to cover completely the surface in order to shade out all algal growth. The TSS in this lagoon as well as the one used in a previous study by Wolverton and McDonald (1979) were reduced to 10 mg/l or less when coverage was complete. Partial coverage allowed the algae sufficient time to become established and contribute to the TSS and probably the BOD_5 of the effluent. A reduction in TSS reduces the TOC accordingly.

The pH in this system was maintained at 7.0 ± 0.2 units when water hyacinths were present in each of the first two experimental periods. This buffering effect by the water hyacinths was also observed in the previous study (Wolverton and McDonald, 1979b).

During the winter months following the first experimental period, a mixture of duckweed of the genera *Spirodela* and *Lemna* (Lemnaceae) flourished. These plants were introduced with the water hyacinth. When the temperatures are warm, water hyacinth is the dominant plant and prevents the duckweed from growing and reproducing at a rapid rate. However, duckweed is more cold tolerant and can grow well after the water hyacinth is killed back. In a properly balanced system, the water hyacinth could be removed every winter and duckweed allowed to substitute.

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